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EP 0 461 761 B1

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Description

This invention relates to sensors and more particularly to inertial sensors such as accelerometers and vibrating gyroscopes.

Conventional gyroscopic sensors for measuring turning rate have utilised the action of Coriolis forces. In a rotating frame of reference, the Coriolis force acting on a rotating mass m is

$$\underline{F} = 2\,\underline{w}\,\underline{Vrel}\,m$$

where

$\underline{F}$ = Coriolis force
$\underline{w}$ = turning rate
m = particle mass
$\underline{Vrel}$ = relative velocity of mass m to fixed reference frame.

The Coriolis force appears perpendicular to the plane containing the particle movement. This characteristic is utilised in conventional spinning-rotor gyroscopes where the axis of the rotor tries to maintain a constant direction in space as a result of the action of the Coriolis forces. Conventional mechanical gyroscopes contain parts such as gimbals, support bearings, motors and rotors which need accurate machining and assembly; these aspects of construction prohibit conventional mechanical gyroscopes from ever becoming an extremely low cost device. Wear on the motors and bearings during operation means that the gyroscope will only meet the performance specifications for a set number of running hours.

GB - A-2156523 discloses a planar inertial sensor having a square shaped planar resonator. GB - A-2164749 discloses a vibrational gyroscope having a vibrating member in the form of a flexible annular shell extending from a flat flexible plate. EP - A - 0307321 discloses a piezoelectric gyroscope having a planar square shaped apertured resonator.

Alternatively, instead of a mass m following a circular trajectory as for the conventional spinning-rotor gyroscope, the mass can be suspended and made to move linearly in simple harmonic motion. Figure 1 shows a simple form of such a vibrating rate sensor which comprises a simple mass 1 suspended in space and excited harmonically along one of its axes, in this example the y axis. Rotation about the z axis which is perpendicular to the y axis F_{DY}, along which the harmonic excitation occurs, results in motion along the third orthogonal x axis F_{cx} is proportional to applied turning rate. This simple arrangement has produced examples of a vibrating-beam rate sensor. One such example is described in the article "Vibrating Angular Rate Sensors" Gates, W D June 1968 Electronics, and comprises a machined bar of ceramic which exhibits piezo-electric properties. The disadvantage of the simple form of vibrating rate sensor described above is that it is an "unbalanced system" which makes it sensitive to linear acceleration.

In order to reduce sensitivity to linear acceleration, Sperry developed a vibrating tuning-fork gyroscope, given the title "Gyrotron", in 1940 [see "A new Space Rate Sensing Instrument" Lyman, J pp 24-30 November 1953 Aeronautical Engineering Review]. This device is shown in Figure 3 and comprises a metallic tuning fork 2 mounted on a thin stem 3, surrounded by associated magnetic drive coils 4 and pickup coils 5. In this structure, the tines were vibrated 180° out of phase and therefore generated torque in the stem which was proportional to rate. The disadvantage of the tuning-fork gyroscope is the requirement to balance accurately the resonant frequencies of the two tines of the tuning fork. More recently, balanced tuning-fork gyroscopic devices have been fabricated by General Precision Industries (USA) in planar form by etching quartz substrates.

The concept of the balanced vibrating tuning fork gyroscope can be extended to an axi-symmetrical shell structure that exhibits identical Eigenmode frequencies. A commercially available rate sensor employing this resonator structure is the START gyroscope manufactured by Marconi (GEC). Patent GB 2061 502A describes this sensor and Figures 4 and 5 show the construction of this hollow, thin-walled cylindrical cup-like resonator structure 6 with bonded piezo-electric transducers 7 positioned on the outside circumference. The bonded piezo-electric transducers permit the excitation and monitoring of vibration in the resonator structure. The frequency of the vibration applied by means of the bonded primary axes transducers is chosen to coincide with a resonance of the structure. The Figures 4 and 5 illustrate the cos 2θ (n=2) mode of vibration which is normally preferred since this gives the maximum radial displacement for a given rate input and drive excitation amplitude. Radial vibration corresponding to applied rate may be sensed along the secondary axes which, for the cos 2θ mode, are at 45° to the primary axes. Figure 5 also shows a form of excitation and detection circuit that could be used to provide a rate output signal; this is described in patents GB2061 502A and GB 2154 739A. The circuit includes a feedback system which excites vibration in the resonator along the primary axes. Radial secondary axes vibrations, resulting from Coriolis forces coupling radial vibration from the primary axes to the secondary axes, can be monitored and suitably amplified so that they may be applied back at the secondary axes to dampen the coupled radial vibrations. A phase detector is used to demodulate the secondary damping signal in order to provide the rate output signal.

For the cylindrical resonator with bonded transducers, balancing of the Eigenmode frequencies of the structure is required for satisfactory gyroscope operation; this balancing operation is an additional manufacturing process which increases cost. An evolution of the cylindrical structure with bonded piezo-electric transducers is to fabricate the entire resonator structure from a piezo-electric material such as radially-polarized ceramic with deposited metallic electrodes to facilitate electrical connection. This is described in patent GB 2061 502A where the shell is rigidly mounted at the base. The advantage of manufacturing a gyroscope resonator from a unitary mass of material is that it permits a low-cost device to be realised. However, the required sintered ceramic materials which exhibit the piezo-electric effect have mechanical properties which are not stable with temperature and time. Moreover, the mounting method employed, for example a stem or end clamp, can result in external stresses unbalancing the resonator and causing the Eigenmodes to have dissimilar frequencies, thereby introducing additional offsets in the detected rate signal.

One object of the present invention is to provide a relatively inexpensive sensor which overcomes many of the disadvantages of previously known systems.

According to one aspect of the present invention there is provided an inertial sensor including a planar vibrating resonator, excitation means for causing the resonator to vibrate, support means for supporting the resonator and for allowing the resonator to vibrate in response to the excitation means and transducer means for sensing movement of the resonator, characterised in that the resonator has a substantially ring or hoop-like structure with inner and outer peripheries extending around a common axis and in that the support means has a plurality of flexible support beams each having a longitudinal stiffness less than a transverse stiffness of the resonator such as to permit the resonator to move relative to the support means in response to linear acceleration, angular acceleration and turning rate.

Embodiments of the invention will now be described, by way of example, with particular reference to Figures 6 to 18 of the accompanying drawings, in which:-

Figure 6 shows a plan view of a ring resonator;
Figure 7 shows a plan view of a hoop-like resonator;
Figure 8 shows a plan view of a planar ring resonator with a central mechanical mount;
Figure 9 shows a plan view of a planar ring resonator with an edge mechanical mount;
Figure 10 shows a plan view of a hoop-like resonator with an edge mechanical mount;
Figure 11 shows three examples of low-stiffness mounts which provide approximately free support to the resonator;
Figure 12 shows the effect of linear and angular acceleration on the resonator ring in its support mount;
Figure 13 shows a triple layer sensor embodiment of the invention;
Figure 14 shows a plan view of the centre layer of the triple layer sensor embodiment;
Figure 15 shows different views of the layers of the triple layer sensor embodiment;
Figure 16 shows a suitable electrode configuration for the resonator transducers;
Figure 17 shows a transducer arrangement in schematic form for a planar ring resonator; and
Figure 18 shows a suitable circuit configuration for use with the resonator which enables sensing of applied turning rate as well as linear and angular acceleration.

Figures 6 and 7 show examples of planar resonators 10 which may be used in the embodiments of the invention to be described. Any ring or hoop-like structure, be it regular or irregular, may be used provided that, when resonating, the Eigenmode frequencies associated with the primary axes P and secondary axes S match as closely as possible so that they are, at least, within the bandwidth of resonance of the resonator. The primary axes P are the axes along which the resonator 10 is excited at a frequency chosen to coincide with its resonant frequency. Turning rate is determined by detecting Coriolis-coupled primary axes P vibrations along the secondary axes S; which, in the cos 2θ mode of operation, are at 45° to the primary axes P. The broken lines in Figure 6 show the effect of the cos 2θ mode of operation on the resonator structure.

In order for the resonator 10 to function correctly, it must be supported in a way that allows it to vibrate as freely as possible. Figure 8 shows a resonator 10 supported by a central mounting region 12 by means of a number of "T"-bar supports 14. The support bars comprise an aperture 16 defined within the mounting region 12, a cross beam 18 and a support beam 20. The longitudinal stiffness of the support beams 20 is designed to be less than the transverse stiffness of the resonator 10 so that the beam-supported resonator approximates a freely vibrating structure. Figures 9 and 10 show resonators 10 supported by an edge mounting 22. Again, low-stiffness "T"-bar supports 14 are used. The resonator 10 of Figure 10 has the form of a square-shaped hoop and includes trimming masses (turning bars) 24 which assist in achieving the desired matching of Eigenmode frequencies.

Figure 11 shows the "T"-bar support in more detail along with two alternatives - an "L"-bar support and and "O"-bar support. All three supports have the longitudinal stiffness of the support beams 20 less than the transverse stiffness of the resonator 10, thus allowing the resonator 10 to approximate a freely-vibrating struc-

ture.

The substrate which forms the resonator 10, mounting 12, 22 and supports 14 may be a stable material such as glass, silicon or quartz wafer or sheet. In addition, the substrate may exhibit isotropic material properties, in which case the resonator 10 will take the general form of a ring. This is the case for amorphous material such as glass, for the <111> surface plane in monocrystalline silicon and also for the Z-cut plane in quartz. In order to fabricate a ring or hoop-like structure from a suitable substrate such as those described above, techniques similar to those used in the semiconductor manufacturing industry can be used. These techniques include dry plasma etching, aqueous acid or alkali etching, laser ablation, laser assisted gas etching, ion-beam sputtering or ion-beam assisted gas etching. Anisotropic alkaline wet etching is not considered to be suitable as other techniques for forming ring-like structures in monocrystalline materials because certain crystalline planes exhibit high relative etching rates. Thus, for these monocrystalline materials etched using anisotropic alkaline etches, it is more appropriate for the resonator to assume a more couplex hoop-like form such as that shown in Figures 7 and 10. These manufacturing techniques are believed to give high accuracy, thus enabling Eigenfrequencies to be easily matched.

Figure 12 shows the effect of linear and angular acceleration on the resonator 10. The coordinate system shown at 26 should be used to assist in interpretation of diagrams A to G. Diagram A shows a side view of the resonator 10 under conditions of no acceleration; B shows the effect of z axis linear acceleration; C shows the effect of angular acceleration about the x axis; D shows the effect of angular acceleration about the y axis; E shows a plan view of the resonator 10 under conditions of no acceleration; F shows the effect of x axis linear acceleration; and G shows the effect of y axis linear acceleration. The resonator shown is of the edge mounted type, although it will be understood that the centrally mounted type would behave in a similar way.

The resonator 10 may be excited into vibration by any suitable transducers. These may function by means of optical, thermal expansion, piezo-electric, electrostatic or electro-magnetic effects, for example. The excitation may be applied to the support structure which carries resonator 10, or directly to the resonator itself.

Resonator vibration along the secondary axes (which gives an indication of turning rate) and lateral or rocking movement of the resonator within its mount 12 or 22 (which gives an indication of linear and angular acceleration) may, for example, be sensed by transducers working electromagnetically, capacitively, optically, piezo-electrically or by means of strain gauges. Capacitive sensing is believed to provide the best method by incorporating electrode plates in close proximity to the resonator 10 in positions above and below the plane of the resonator.

A triple substrate embodiment of the invention which employs capacitive sensing is shown in Figures 13 to 18. The resonator 10 is formed in the centre plate 50 which comprises a suitable substrate and lies between upper plate 51 and lower plate 52. The centre plate 50 may be <111> cut silicon, and the upper and lower plates may be glass, quartz or fused silica in order to permit viewing of the centre plate 50, thus allowing alignment with the resonator 10 and the matching of Eigenfrequencies by laser ablation of the resonator 10 (and trimming masses, if appropriate). The centre plate 50 comprises edge mounting 22 which supports ring resonator 10 by means of a series of "L"-bar supports 53. The conductive centre substrate is uniformly coated with insulating silicon dioxide or silicon nitride. Electrodes 54 are formed on the upper and lower faces of the coated resonator 10, these being electrically connected to the peripheral connection pads 55 by way of tracks 56 that run from the pads 55 and along the "L"-beams 53. The centre substrate is electrically connected to some suitable fixed potential so that capacitive cross-talk cannot occur between tracks 56 via the substrate. The upper and lower plates 51 and 52 have a similar design to one another, and each include annular electrodes 57 formed in a recess 58. When the sensor is assembled, the recesses 58 of the upper and lower plates 51 and 52 are arranged so that their electrodes 57 overlap the electrodes 54 of the centre plate 50. A constant bias potential is applied to each of the electrodes 57 in order that electrostatic forces can be generated and resonator ring vibration can be detected by capacitive pick-up, the signals from the electrodes 57 being made available at terminals 60.

A suitable design for the electrodes of each of the plates is shown in Figure 16. They may each comprise a series of concentric electrode strips 61, having a similar periodicity in the electrodes of the upper, lower and central plates 51, 52 and 50. As shown generally at 50, the electrode strips of the upper and lower plates 51 and 52 are skewed relative to the electrode strips of the centre plate 50, ie the electrode strips of the outer plates 51, 52 and the central plate 50 are not laterally aligned. This arrangement allows lateral and normal forces F_y and F_x to be applied to the resonator 10 by applying voltages to the electrodes 54 of the centre plate 50. Likewise, detection of both lateral and normal movement is made possible by appropriate signal processing (such as that to be described later with reference to Figure 18) applied to the signal current generator in electrodes 54, these electrodes functioning as vibration pick-up transducers. The signal processing may excite and detect cos 2θ mode along the primary axes, detect and dampen cos 2θ mode along the secondary axes, and detect lateral, vertical and rocking motions of the resonator 10 within its "L"-beam support mount.

Figure 17 show schematically the positions of two sets of transducers U1 -U8 and L1 -L8 located above and below the resonator respectively. If, for example, each of the transducers U1, L1, U2, etc took the form of the capacitive sensor described above, each transducer would comprise two sets of concentric electrode strips, one set located on the upper or lower surface of the resonator, and the other set located on the upper or lower plates 51 or 52 of the sensor. Each transducer produces an output signal which is representative of the distance between its respective sets of the electrode strips.

Thus, the output of the transducers gives an indication of acceleration and turning rate. By way of example, if we assume that (a) transducers U4, L4, U8 and L8 are used to excite primary cos 20 mode vibration; (b) downward movement of the lower transducers L1-L8 produces a similar output signal sense to upward movement of the upper transducers U1-U8; and (c) lateral movement of the resonator causes a similar sense of output signal from the upper and lower transducers, the signal summations shown in the table below permit the detection of acceleration and turning rate applied to the sensor when interpreted using the co-ordinate system shown at 64.

Inertial measurement	Signal summation
Z - axis linear acceleration	(U2 + U6) - (L2 + L6)
X - axis linear acceleration	(U8 + L8) - (L4 + U4)
Y - axis linear acceleration	(U6 + L6) - (L2 + U2)
Z - axis turning rate	(U7 + U3 + L7 + L3)
Angular acceleration about X - axis	(U6 + L2) - (U2 + L6)
Angular acceleration about Y - axis	(U8 + L4) - (U4 + L8)

Figure 18 shows one example of a suitable circuit configuration which may be used to determine turning

rate and linear and angular acceleration applied to the sensor. The signals 51 from the resonator transducers 68 at the primary and secondary axes (such as U1-U8 and L1-L8 described above) are analogue sinusoidal carrier signals, some of which may be amplitude modulated depending on acceleration and turning rate applied to the sensor. Signals S_1 are amplified and buffered by preamplifiers 70 to produce signals S2 which are passed to summing and differencing network 74. The network 74 performs appropriate addition and subtraction (see table, for example) of input analogue signals S_2 depending on the transducer configuration so as to produce sinusoidal analogue signals S_3, S_5 and S_7. Signal S_3 is a sinusoid modulated in response to lateral movement and rocking motion of the resonator within its mount (and therefore representative of linear and angular acceleration). Signal S_5 corresponds to the detected primary cos 2θ mode vibration of the resonator, and signal S_7 corresponds to the detected secondary cos 2θ mode vibration of the resonator resulting from Coriolis-coupled vibrations from the primary mode. Signal S_5 is passed to the primary axes excitation unit 78 where, for example, the signal is phase shifted by 90° to produce signal S6 which is applied to the resonator tranducers 68 which excite the primary mode vibrations. Excitation unit 78 also converts signal S_5 into a square wave logic gating signal S_8, the purpose of which will be described later.

Signal S_7 is passed to secondary axes damping unit 80 along with logic gating signal S_8. The unit 80 operates in such a way that the damping signal output S_{10} has a frequency equivalent to signal S_8, but with its amplitude set according to the value of signal S_7 in order to dampen rate coupled secondary vivrations.

Signal S_{10} is also applied to demodulator 82 where it is demodulated with respect to logic gating signal S_8, the resultant signal S_9 being representative of turning rate.

Likewise, signal S_3 is applied to a second demodulator 84 where it is also demodulated with respect to logic gating signal S_8, the resultant signals S_{11} and S_{12} being representative linear and angular acceleration respectively.

Any cross sensitivity between detected acceleration and turning rate in signals S_9, S_{11} and S_{12} may be compensated in unit 86 by correcting any linear vibration sensitivity in the signal S_9 representative of measured rate by using the acceleration signals S_{11} and S_{12}. The sensor output signals S_{13} represent angular acceleration, linear acceleration and turning rate may be in either analogue or digitised format.

In order to overcome likely signal crosstalk problems between the primary axes excitation and secondary axes detection, the drive may be applied in bursts and the pick-up monitored in the periods between drive bursts. This is feasible if the structure has high resonance Q and the drive burst duration is less than the decay time constant of the excited mode vibrations.

It should be noted that any shape of ring or hoop-like structure may be used in the fabrication of this type of inertial sensor provided that the substrate can be etched to ensure that the Eigenmodes excited and detected at primary and secondary axes have nearly identical Eigenfrequencies. With reference to the resonator supported by mechanical mounts such as "T"-bars or "L" bars, it should be noted that the number of supports required may be varied according to the requirements and shape of the resonator structure.

It should also be noted that the configurations illustrated use the cost 2θ mode as shown in Figure 6. This mode is believed to be advantageous because it gives maximum radial displacement for a given rate input and excitation amplitude, although the sensor could use other modes, for example cos 3θ, cos 4θ, etc.

Claims

1. An inertial sensor including a planar vibratory resonator (10), excitation means (57) for causing the resonator (10) to vibrate, support means for supporting the resonator (10) and for allowing the resonator (10) to vibrate in response to the excitation means (57) and transducer means (U1 to U8 and L1 to L8) for sensing movement of the resonator (10), characterised in that the resonator (10) has a substantially ring or hoop-like structure with inner and outer peripheries extending around a common axis and in that the support means (12, 22) has a plurality of flexible support beams (20, 53) each having a longitudinal stiffness less than a transverse stiffness of the resonator (10) such as to permit the resonator (10) to move relative to the support means in response to linear acceleration, angular acceleration and turning rate.

2. A sensor according to claim 1, wherein the excitation means (57) includes transducers which function optically, by thermal expansion, piezo-electrically, electrostatically or electromagnetically, and which operate to apply excitation to the resonator (10) either directly or indirectly via the support structure.

3. A sensor according to claim 1 or claim 2, wherein the resonator (10) is ring-like in shape and wherein the support means (12) has a central disc like mounting region coupled to the inner periphery of the ring-like shaped resonator (10) by said support beams (20) which extend radially between said mounting region

and resonator (10), an aperture (16) being provided in the mounting region adjacent each beam (20) to provide the beams (20) with a T or L shape.

4. A sensor according to claim 1 or claim 2, wherein the resonator (10) is ring-like in shape and wherein the support means (22) surrounds said resonator (10) and is coupled to the outer periphery of the ring-like shaped resonator (10) by said support beams (20, 53) which extend radially between said support means (22) and resonator (10), an aperture (16) being provided in the support means adjacent each beam (20, 53) to provide the beams (20) with a T or L shape.

5. A sensor according to claim 1 or claim 2, wherein the resonator (10) is in the form of a square shaped hoop, and wherein the support means (22) surrounds said resonator (10) and is coupled to the outer periphery of the resonator (10) by said support beams (20) which extend perpendicularly and radially between the support means (22) and resonator (10), an aperture (16) being provided in the support means adjacent each beam (20) to provide the beams (20) with a T or L shape (18, 20).

6. A sensor according to claim 1, wherein each support beam (20) has a substantially O shaped region (18) with an aperture (16) therein.

7. A sensor according to claim 4, wherein said excitation means comprises a plurality of pairs of electrodes (54, 57) positioned around said resonator (10) each of said electrodes comprising a series of concentric electrode strips (61).

8. A sensor according to claim 7 wherein the strips of the respective series of concentric electrode strips (61) of each pair of electrodes (54, 57) are not laterally aligned.

9. A sensor according to claim 1, wherein said excitation means is periodically inoperative and wherein signals from said transducer means representative of movement of said resonator (10) are monitored during the inoperative periods.

10. A sensor according to claim 1, wherein the resonator (10), support means (12, 22) and support beams (20, 53) are configured such as to enable measurement of angular turning rate about the common axis of the resonator (10), measurement of angular turning acceleration about any axis perpendicular to the common axis of the resonator (10) and measurement of linear acceleration about any axis perpendicular to, or aligned to, the common axis of the resonator (10).

11. A sensor according to claim 1, including a circuit wherein signals from said transducer means (U1 to U8 and L1 to L8) representative of movement of said resonator (10) are processed to produce a first signal representative of linear acceleration of said sensor and a second signal representative of turning rate of said sensor, said second signal being modified by said first signal in order to compensate of any linear acceleration component in said second signal.

12. A sensor according to claim 1, including a circuit wherein signals from said transducer means (U1 to U8) representative of movement of said resonator (10) are processed to produce a first signal representative of angular acceleration of said sensor and a second signal representative of turning rate of said sensor, said second signal being modified by said first signal in order to compensate of any angular acceleration component.

Patentansprüche

1. Trägheitssensor mit einem ebenen Vibrationsresonator (10), mit einer Erregereinrichtung (57), die den Resonator (10) in Vibration versetzt, mit Stützmitteln, um den Resonator (10) in Abhängigkeit von der Erregereinrichtung (57) in Vibration zu versetzen, und mit Wandlern (U1 bis U8 und L1 bis L8) zur Feststellung der Bewegung des Resonators (10),
dadurch gekennzeichnet, daß der Resonator (10) einen im wesentlichen ringförmigen oder reifenförmigen Aufbau besitzt, wobei dessen äußerer und innerer Umfang sich um eine gemeinsame Achse erstreckt, und daß die Stützmittel (12, 22) aus mehreren flexiblen Traggliedern (20, 53) bestehen, die jeweils eine in Längsrichtung verlaufende Steifheit besitzen, die kleiner ist als die Quersteifheit des Resonators (10), so daß sich der Resonator (10) relativ zu den Stützmitteln gemäß einer linearen Beschleunigung, einer

Winkelbeschleunigung und einer Winkelgeschwindigkeit bewegen kann.

2. Sensor nach Anspruch 1, bei welchem die Erregereinrichtung (57) Wandler aufweist, die optisch, durch thermische Expansion, piezo-elektrisch, elektrostatisch oder elektromagnetisch arbeiten und ihre Erregung an den Resonator (10) entweder direkt oder indirekt über die Stützmittel anlegen.

3. Sensor nach den Ansprüchen 1 oder 2, bei welchem der Resonator (10) ringartig gestaltet ist und die Stützmittel (12) einen zentralen scheibenförmig ausgebildeten Bereich besitzen, der mit dem inneren Umfang des ringförmig gestalteten Resonators (10) über Stützglieder (20) gelagert ist, die sich radial zwischen dem Lagerbereich und dem Resonator (10) erstrecken, wobei eine Öffnung (16) im Lagerbereich benachbart zu jedem Stützglied (20) vorgesehen ist, um Stützglieder (20) mit T-Form oder L-Form zu bilden.

4. Sensor nach den Ansprüchen 1 oder 2, bei welchem der Resonator (10) ringförmig gestaltet ist und die Stützglieder (22) den Resonator (10) umgeben und mit dem äußeren Umfang des ringförmigen Resonators (10) über die Stützglieder (20, 53) gekuppelt sind, die sich radial zwischen den Stützmitteln (22) und dem Resonator (10) erstrecken, wobei eine Öffnung (16) in den Stützmitteln benachbart zu jedem Stützglied (20, 53) vorgesehen ist, um die Stützglieder (20) mit T-Gestalt oder L-Gestalt zu versehen.

5. Sensor nach Anspruch 1 oder 2, bei welchem der Resonator (10) die Form eines quadratisch gestalteten Reifens besitzt, wobei die Stützmittel den Resonator (10) umgeben und mit dem äußeren Umfang des Resonators (10) durch die Stützglieder (20) verbunden sind, die sich senkrecht und radial zwischen den Stützmitteln (22) und dem Resonator (10) erstrecken, wobei eine Öffnung (16) in den Tragmitteln benachbart zu jedem Tragglied (20) vorgesehen ist, um den Traggliedern (20) eine T-Form oder eine L-Form (18, 20) zu verleihen.

6. Sensor nach Anspruch 1, bei welchem jedes Stützglied (20) einen im wesentlichen O-förmigen Bereich (18) und eine Öffnung (16) darin aufweist.

7. Sensor nach Anspruch 4, bei welchem die Erregereinrichtung mehrere Elektrodenpaare (54, 57) aufweist, die um den Resonator (10) herum angeordnet sind, wobei die Elektroden aus einer Reihe konzentrischer Elektrodenstreifen (61) bestehen.

8. Sensor nach Anspruch 7, bei welchem die Streifen der jeweiligen konzentrischen Elektrodenstreifen (61) jedes Elektrodenpaares (54, 57) seitlich nicht ausgerichtet sind.

9. Sensor nach Anspruch 1, bei welchem die Erregereinrichtung periodisch unwirksam ist und bei welchem die Signale vom Wandler, die repräsentativ sind für die Bewegung des Resonators (10), während der unwirksamen Periode überwacht werden.

10. Sensor nach Anspruch 1, bei welchem der Resonator (10), die Stützmittel (12, 22) und die Stützglieder (20, 53) so ausgebildet sind, daß eine Messung der Winkelgeschwindigkeit um die gemeinsame Achse des Resonators (10), eine Messung der Winkelbeschleunigung um jede Achse senkrecht zur gemeinsamen Achse des Resonators (10) und eine Messung der linearen Beschleunigung um jede Achse senkrecht zu der gemeinsamen Achse des Resonators (10) oder ausgerichtet hierauf erfolgen kann.

11. Sensor nach Anspruch 1, mit einer Schaltung, bei welcher die Signale von den Wandlern (U1 bis U8 und L1 bis L8), die repräsentativ sind für die Bewegung des Resonators (10), so verarbeitet werden, daß ein erstes Signal erzeugt wird, welches repräsentativ ist für die Linearbeschleunigung des Sensors, und ein zweites Signal erzeugt wird, welches repräsentativ ist für die Winkelgeschwindigkeit des Sensors, wobei das zweite Signal durch das erste Signal modifiziert wird, um irgendwelche linearen Beschleunigungskomponenten in dem zweiten Signal zu kompensieren.

12. Sensor nach Anspruch 1, bei welchem die Signale von den Wandlern (U1 bis U8), die für die Bewegung des Resonators (10) repräsentativ sind, so verarbeitet werden, daß ein erstes Signal erzeugt wird, welches repräsentativ ist für die Winkelbeschleunigung des Sensors, und ein zweites Signal, welches repräsentativ ist für die Winkelgeschwindigkeit des Sensors, wobei das zweite Signal durch das erste Signal modifiziert wird, um etwaige Komponenten der Winkelbeschleunigung zu kompensieren.

Revendications

1. Capteur inertiel comprenant un résonateur vibratoire plan (10), un moyen d'excitation (57) pour forcer le résonateur (10) à vibrer, un moyen formant support pour supporter le résonateur (10) et pour permettre au résonateur (10) de vibrer en réponse au moyen d'excitation (57) et un moyen transducteur (U1 à U8 et L1 à L8) pour capter le mouvement du résonateur (10), caractérisé en ce que le résonateur (10) a une structure sensiblement en forme d'anneau ou de bague avec des périphéries intérieure et extérieure s'étendant autour d'un axe commun, et en ce que le moyen formant support (12, 22) a une pluralité de rayons de support flexibles (20, 53), chacun ayant une rigidité longitudinale plus petite que la rigidité transversale du résonateur (10), permettant ainsi au résonateur (10) de se déplacer par rapport au moyen formant support en réponse à une accélération linéaire, une accélération angulaire et une vitesse de rotation.

2. Capteur selon la revendication 1, dans lequel le moyen d'excitation (57) comprend des transducteurs qui fonctionnent optiquement, par dilatation thermique, par effet piézoélectrique, par effet électrostatique ou par effet électromagnétique, et qui agissent pour appliquer une excitation au résonateur (10), soit directement, soit indirectement par l'intermédiaire de la structure support.

3. Capteur selon la revendication 1 ou la revendication 2, dans lequel le résonateur (10) est en forme d'anneau et dans lequel le moyen formant support (12) a une zone centrale de montage en forme de disque relié à la périphérie intérieure du résonateur (10) en forme d'anneau par lesdits rayons de support (20) qui s'étendent radialement entre ladite zone de montage et le résonateur (10), une ouverture (16) étant prévue dans la zone de montage adjacente à chaque rayon (20) pour donner aux rayons (20) une forme en T ou en L.

4. Capteur selon la revendication 1 ou la revendication 2, dans lequel le résonateur (10) est en forme d'anneau et dans lequel le moyen formant support (22) entoure ledit résonateur (10) et est relié à la périphérie extérieure du résonateur (10) en forme d'anneau par lesdits rayons de support (20, 53) qui s'étendent radialement entre ledit moyen formant support (22) et le résonateur (10), une ouverture (16) étant prévue dans le moyen formant support adjacent à chaque rayon (20, 53) pour donner aux rayons (20) une forme en T ou en L.

5. Capteur selon la revendication 1 ou la revendication 2, dans lequel le résonateur (10) est en forme de bague de forme carrée, et dans lequel le moyen formant support (22) entoure ledit résonateur (10) et est relié à la périphérie extérieure du résonateur (10) par lesdits rayons de support (20) qui s'étendent perpendiculairement et radialement entre le moyen formant support (22) et le résonateur (10), une ouverture (16) étant prévue dans le moyen formant support adjacent à chaque rayon (20) pour donner aux rayons (20) une forme en T ou en L (18, 20).

6. Capteur selon la revendication 1, dans lequel chaque rayon de support (20) a une zone (18) sensiblement en forme de O avec une ouverture (16) à l'intérieur.

7. Capteur selon la revendication 4, dans lequel ledit moyen d'excitation comprend une pluralité de paires d'électrodes (54, 57) positionnées autour dudit résonateur (10), chacune desdites électrodes comprenant une série de bandes d'électrodes concentriques (61).

8. Capteur selon la revendication 7, dans lequel les bandes de la série respective de bandes d'électrodes concentriques (61) de chaque paire d'électrodes (54, 57) ne sont pas alignées latéralement.

9. Capteur selon la revendication 1, dans lequel ledit moyen d'excitation est périodiquement au repos et dans lequel les signaux provenant dudit moyen formant transducteur, représentant le mouvement dudit résonateur (10), sont contrôlés pendant les périodes de repos.

10. Capteur selon la revendication 1, dans lequel le résonateur (10), le moyen formant support (12, 22) et les rayons de support (20, 53) sont conformés de façon à permettre la mesure de vitesse de rotation angulaire autour d'un axe commun du résonateur (10), la mesure d'accélération de rotation angulaire autour de tout axe perpendiculaire à l'axe commun du résonateur (10) et la mesure d'accélération linéaire suivant tout axe perpendiculaire à, ou aligné avec, l'axe commun du résonateur (10).

11. Capteur selon la revendication 1, comprenant un circuit dans lequel les signaux provenant dudit moyen

formant transducteur (U1 à U8 et L1 à L8) représentant le mouvement dudit résonateur (10) sont traités pour produire un premier signal représentant l'accélération linéaire dudit capteur et un second signal représentant la vitesse de rotation dudit capteur, ledit second signal étant modifié par ledit premier signal afin de compenser toute composante d'accélération linéaire dudit second signal.

12. Capteur selon la revendication 1, comprenant un circuit dans lequel les signaux provenant dudit moyen formant transducteur (U1 à U8) représentant le mouvement dudit résonateur (10) sont traités pour produire un premier signal représentant l'accélération angulaire dudit capteur et un second signal représentant la vitesse de rotation dudit capteur, ledit second signal étant modifié par le premier signal afin de compenser toute composante d'accélération angulaire.

Fig.1.

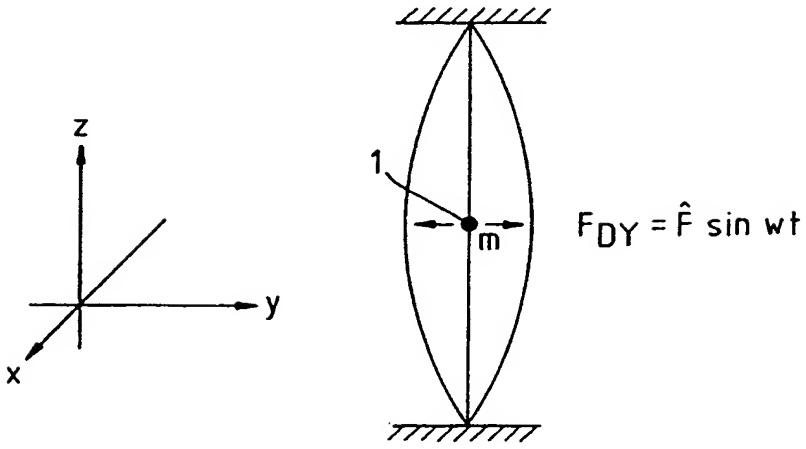
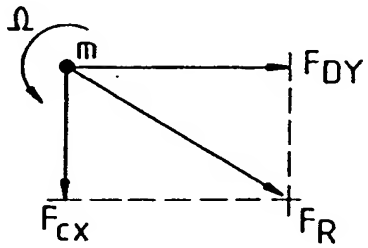


Fig.2.

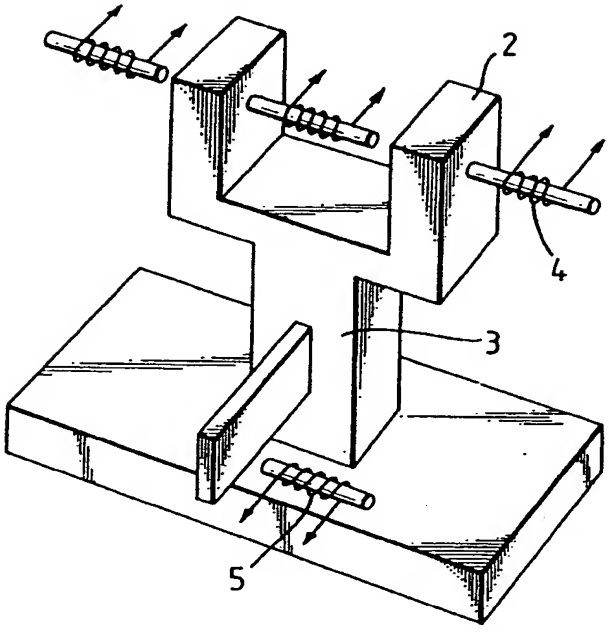


F_{DY} = DRIVE EXCITATION FORCE IN y DIRECTION

F_{cx} = CORIOLIS FORCE IN x DIRECTION DUE TO APPLICATION OF TURNING RATE Ω

F_R = RESULTANT FORCE FROM F_{DY} AND F_{cx}

Fig.3.



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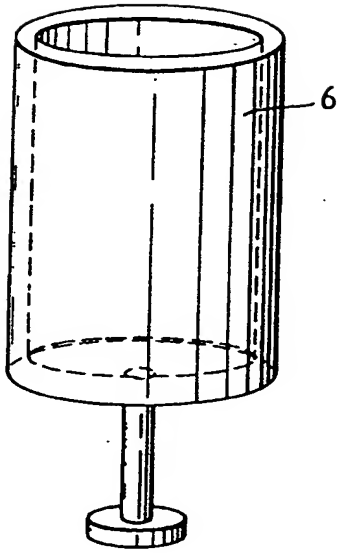
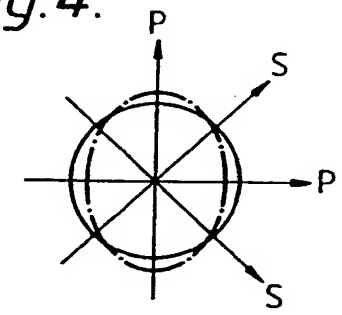
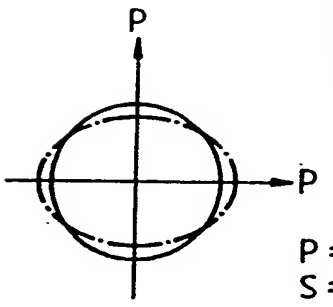






DOTTED LINES INDICATE cos 2θ MODE VIBRATION PATTERN

P = PRIMARY AXES
S = SECONDARY AXES

Fig.5.

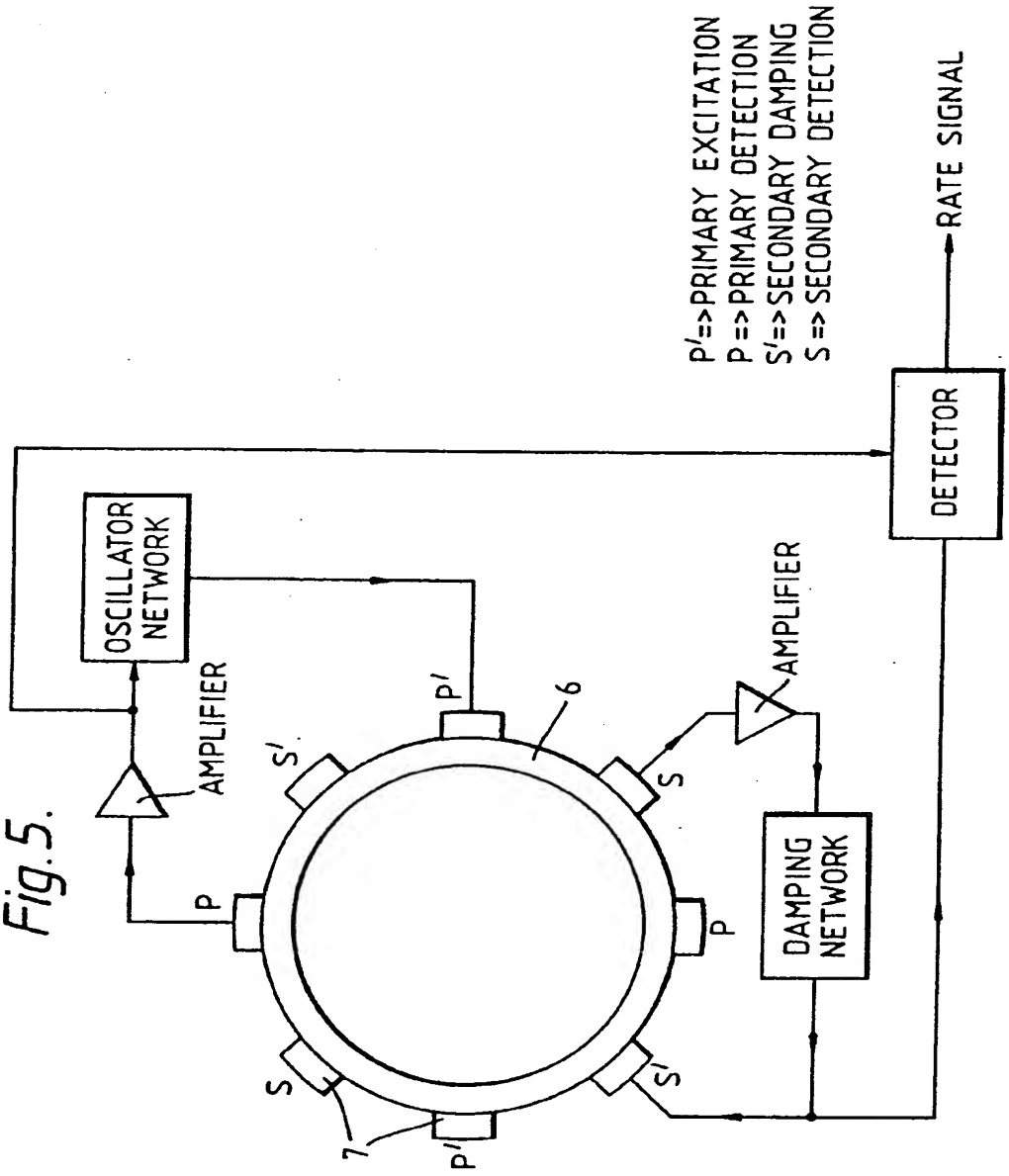

P'=>PRIMARY EXCITATION
P =>PRIMARY DETECTION
S'=>SECONDARY DAMPING
S =>SECONDARY DETECTION
RATE SIGNAL
DETECTOR
OSCILLATOR NETWORK
AMPLIFIER
AMPLIFIER
DAMPING NETWORK
P
P'
S
S'
6
7

Fig.6.

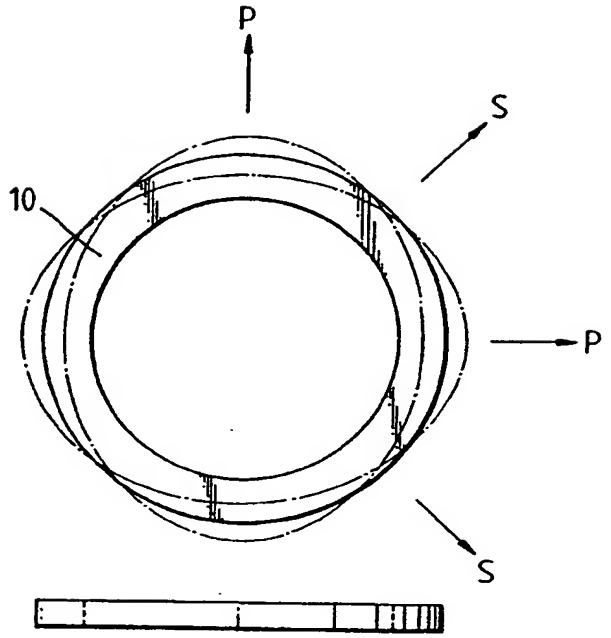
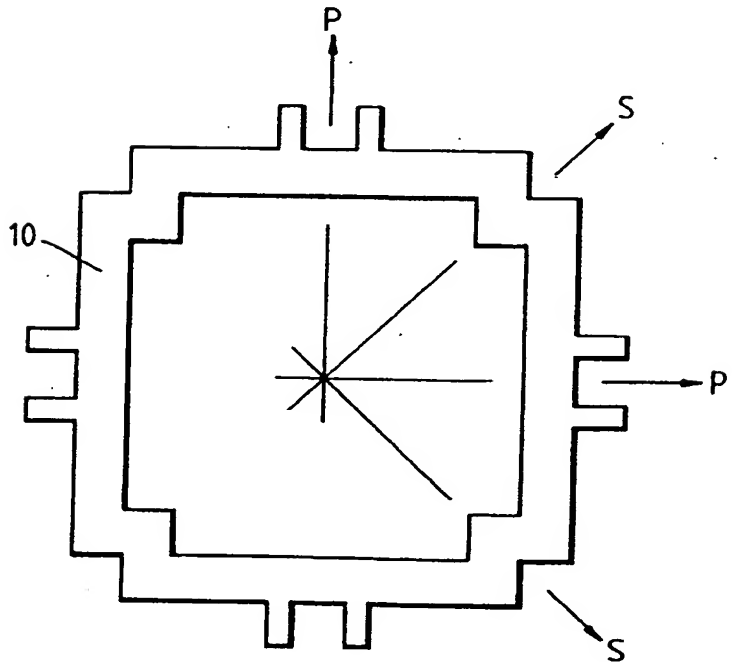


Fig.7.



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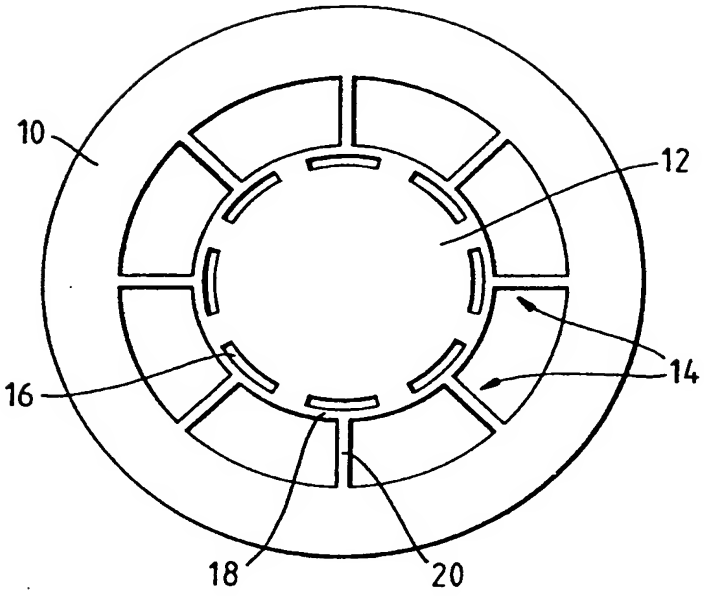

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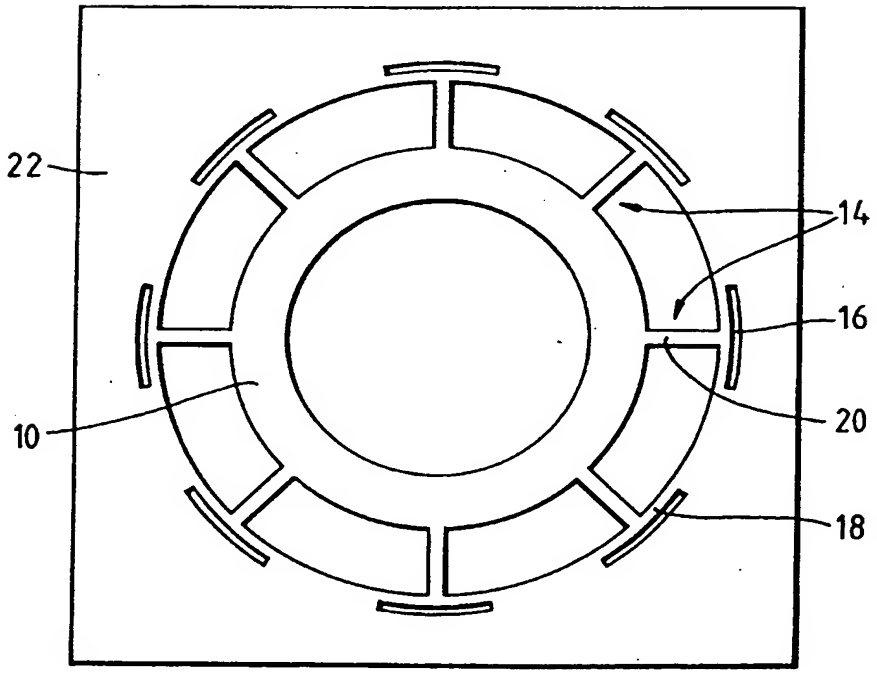


Fig. 10.

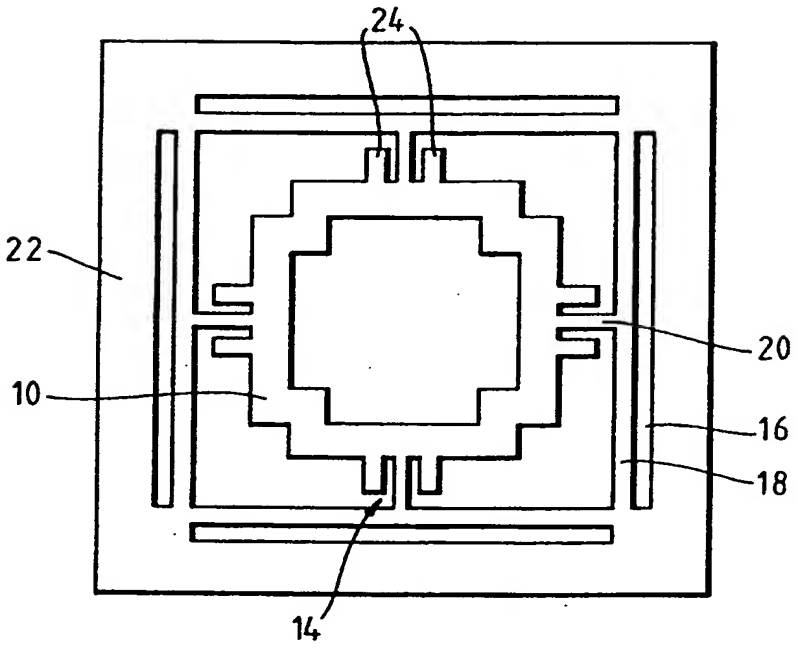
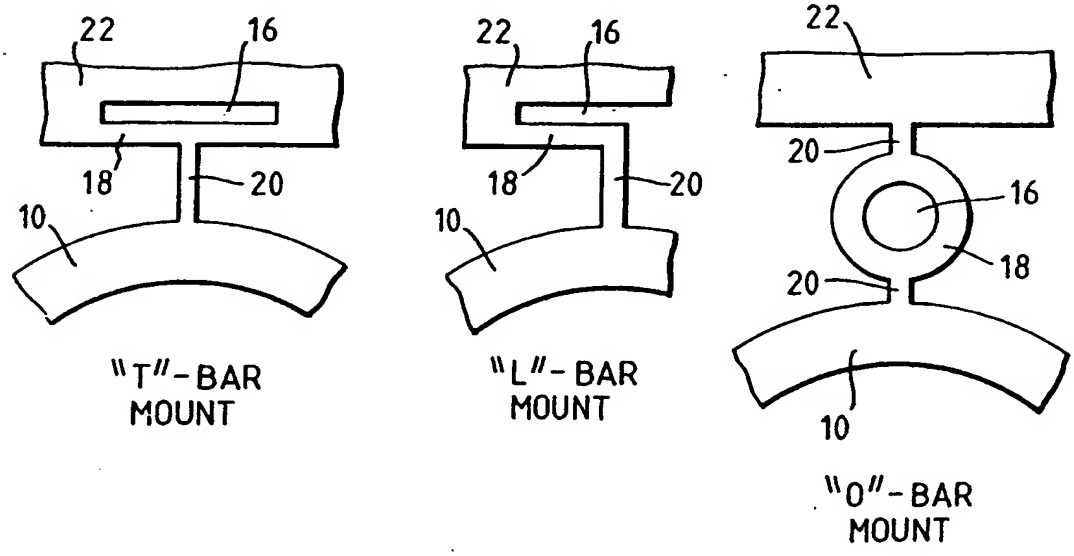

24
22
20
10
16
18
14

Fig. 11.


22
16
18
20
10
"T"-BAR MOUNT
22
16
18
20
10
"L"-BAR MOUNT
22
20
16
18
20
10
"O"-BAR MOUNT

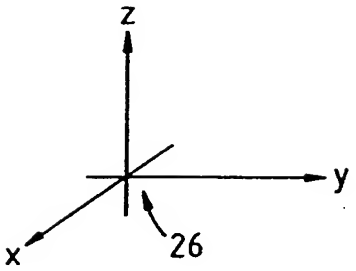
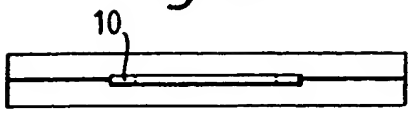


Fig. 12A.



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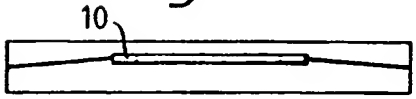


Fig. 12C.

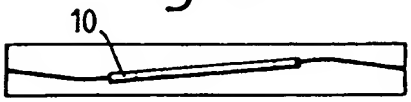


Fig. 12D.

Fig. 12E.

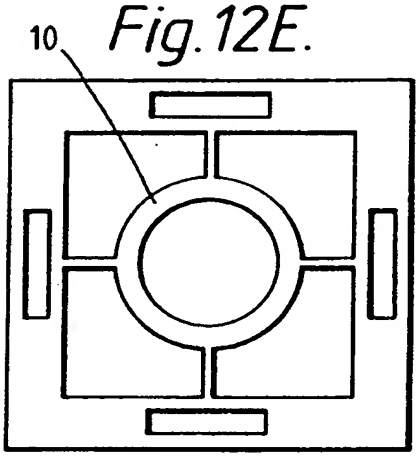


Fig. 12F.

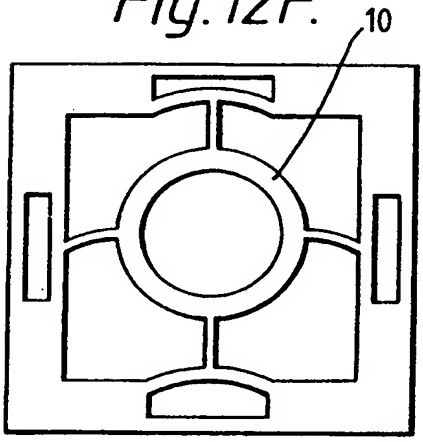


Fig. 12G.

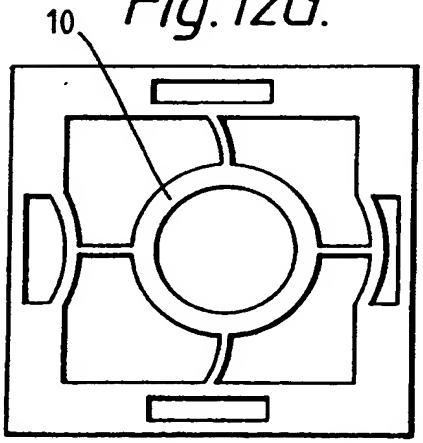
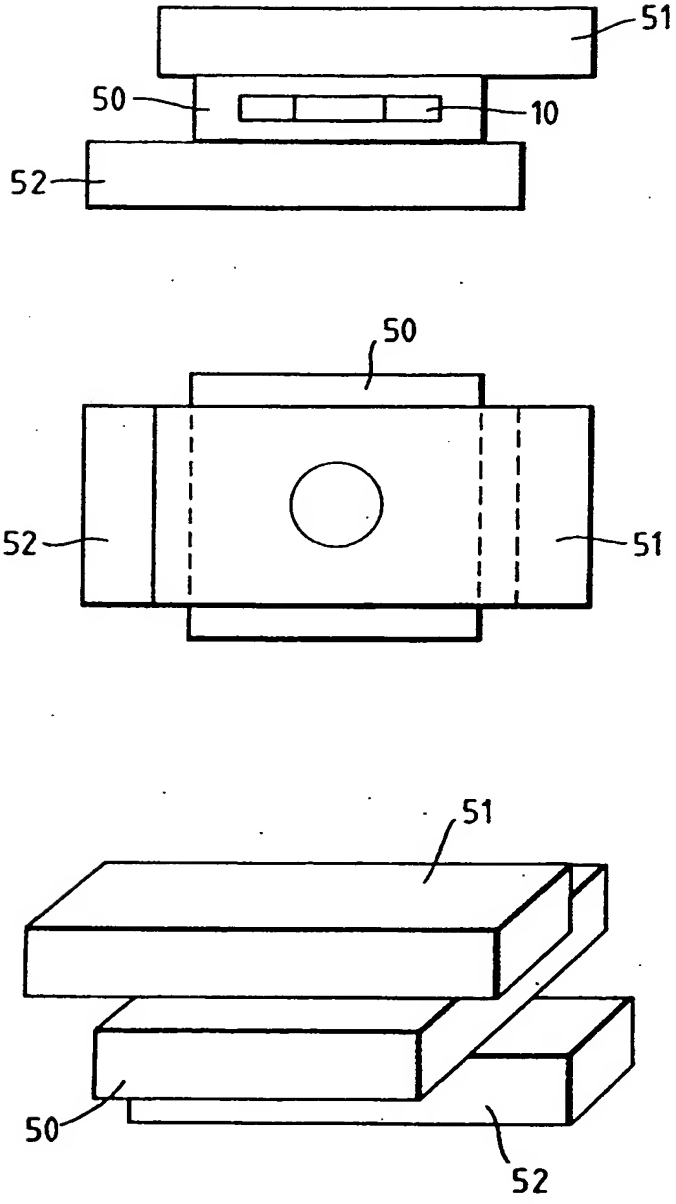


Fig.13.



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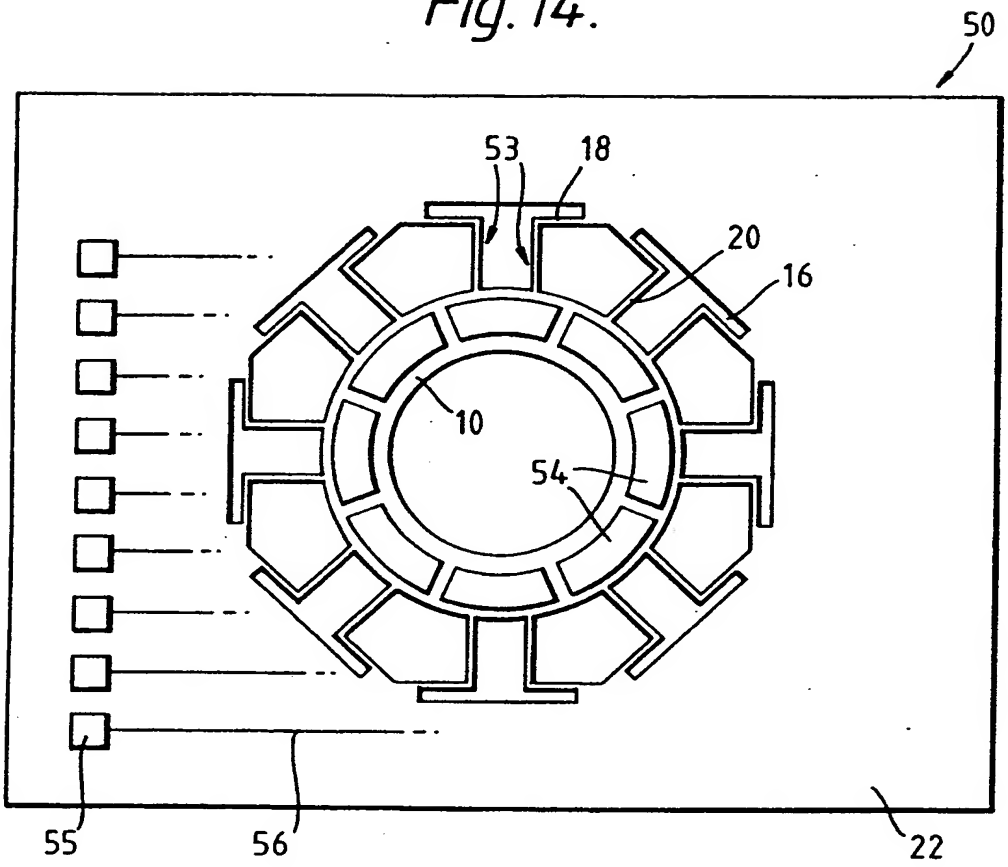

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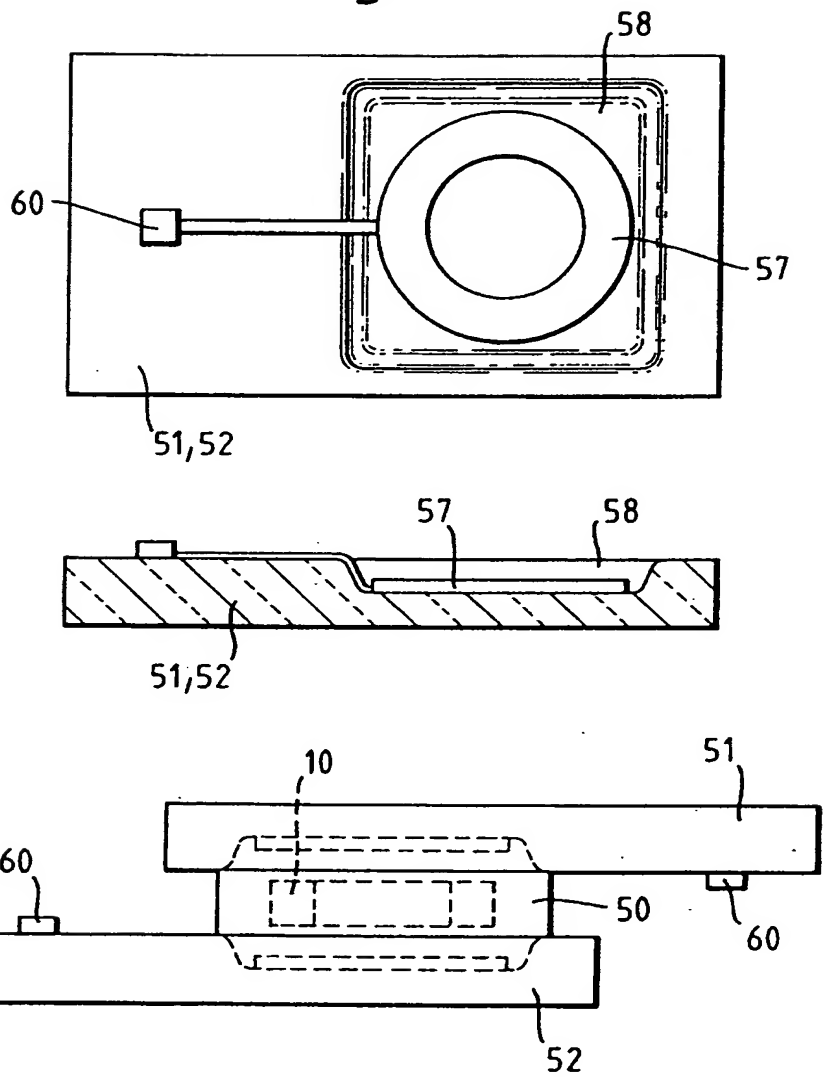

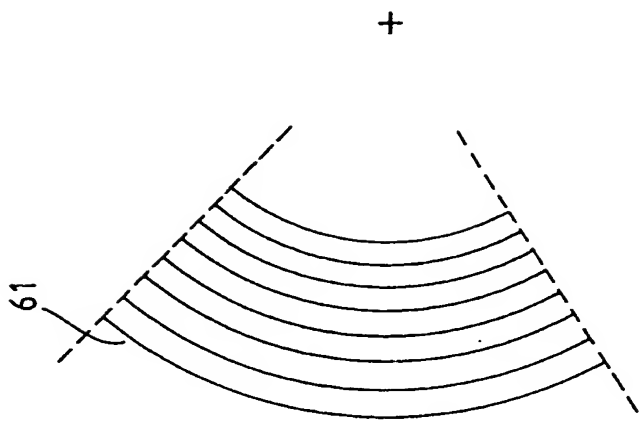

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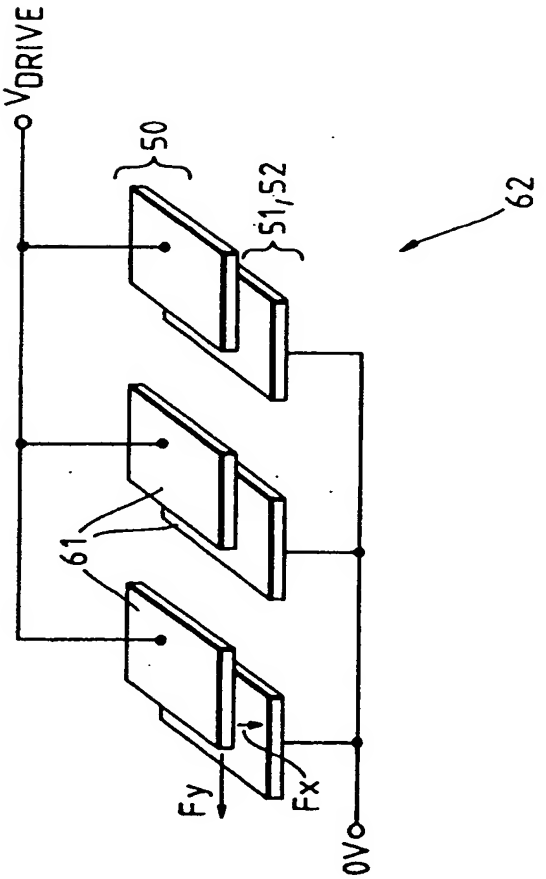

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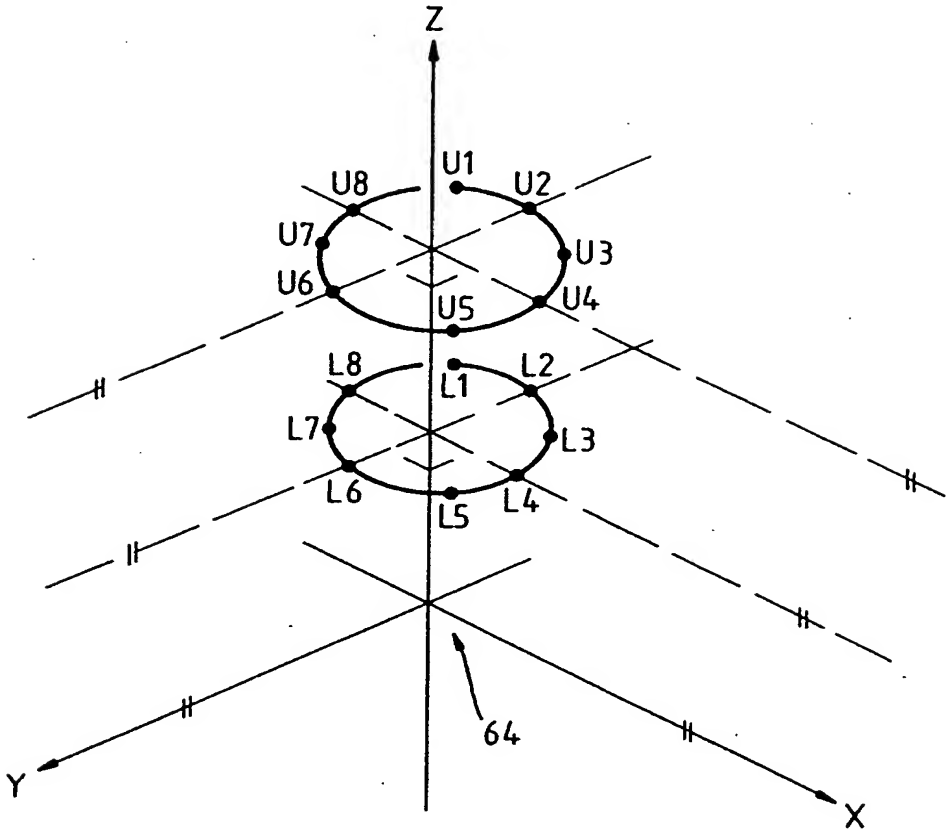

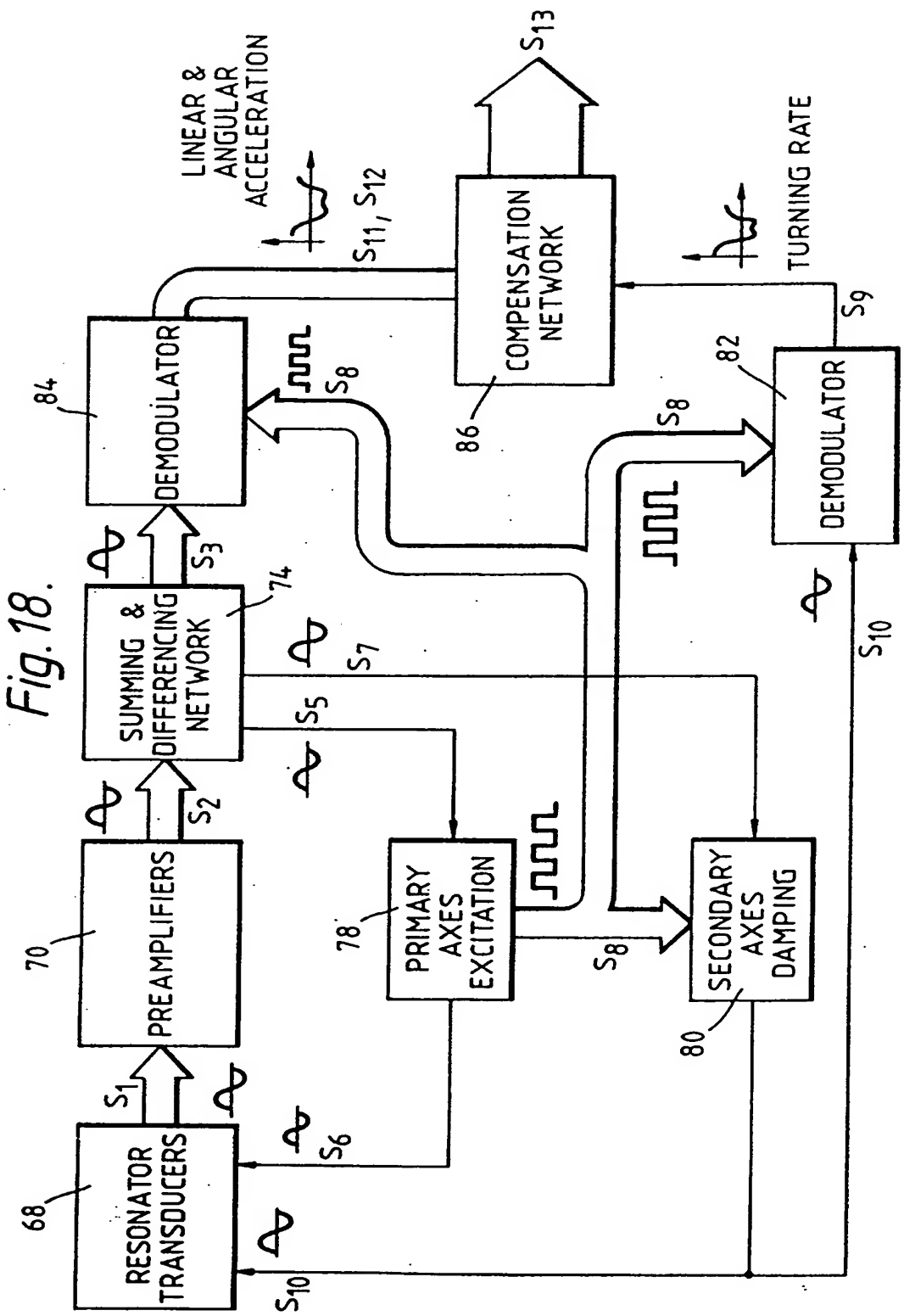
LINEAR & ANGULAR ACCELERATION
S_{11}, S_{12}
S_{13}
COMPENSATION NETWORK
86
TURNING RATE
S_9
82
DEMODULATOR
84
DEMODULATOR
S_8
S_8
S_3
74
SUMMING & DIFFERENCING NETWORK
S_7
S_5
S_2
S_{10}
70
PREAMPLIFIERS
78
PRIMARY AXES EXCITATION
S_8
SECONDARY AXES DAMPING
80
S_1
S_6
68
RESONATOR TRANSDUCERS
S_{10}

Fig. 18.

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